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High Pulse Power Lithium Ion Cells

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Introduction to Yardney/Lithion Inc.

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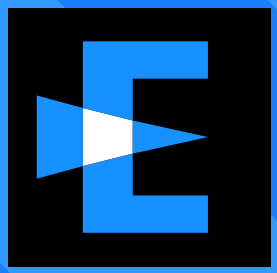
09/02/16

Lithion Inc.



Ener-Tek International, Inc.

Yardney TECHNICAL PRODUCTS, INC.

Silver-Zinc
Silver-Cadmium
Silver Chloride
Metal-Air

Lithion Inc.

Lithium-ion
Rechargeable
Liquid and Polymer
Electrolyte

09/02/16

Yardney TECHNICAL PRODUCTS, INC.

Glossary

- C Rate: A charge or discharge rate that is equal to the nominal capacity
- Depth of Discharge: The ratio of the capacity removed from a cell or battery to the rated capacity (usually expressed as a percent)
- Energy Density: Wh/liter and/or Wh/kg
- Polarization: A decrease in potential caused by passage of an electric current

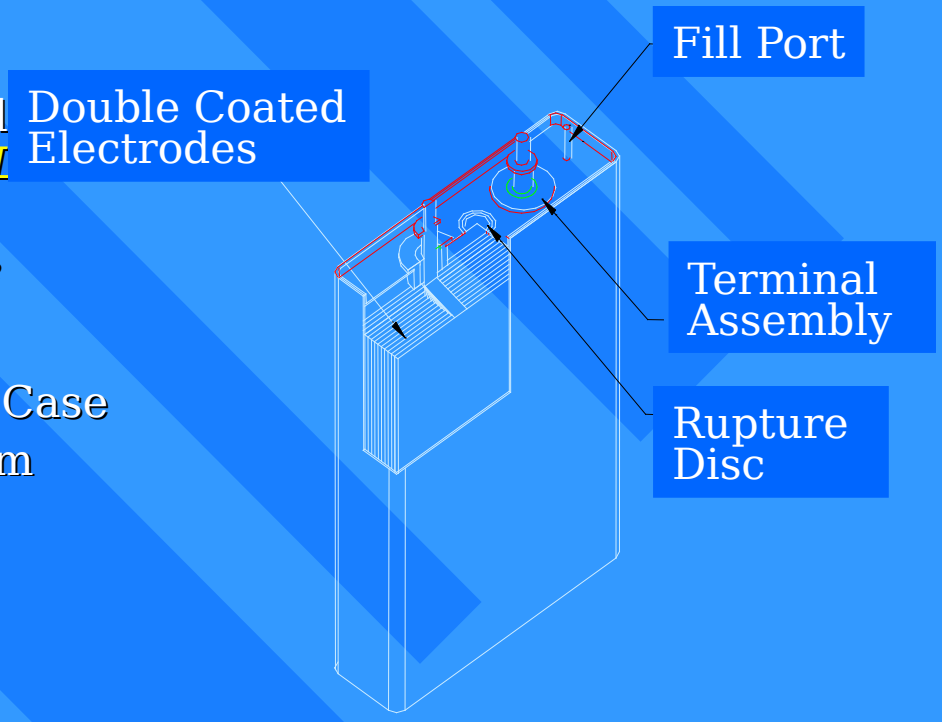
Advantages of Lithium-ion

- Unique Weight and Volume Solution
  - Cell Level: 185 Wh/kg; 480 Wh/l
  - Battery Level: 168 Wh/kg; 435 Wh/l
  - Lower Launch Weight for Same Power Requirements
- Extreme Long Life
  - Several Tens of Thousands of Low DOD cycles Expected
    - More than 1,000 100% DOD Cycles Demonstrated
    - Over 11,000 40% DOD cycles to date
- Very High Efficiency
  - Typically >95% Energy Efficient
    - Less heat generation/power loss

Lithium-ion Cell Design

Li-ion Prismatic Cell

- Internal Components
  - » Intercalation Anode and Cathode ***No Metallic L***
  - » Organic Solvent Based Electrolyte ***Flammable***
- Construction
  - » Hermetically sealed SS Case
  - » Cell Stack insulated from Case
  - » Glass-to-metal Seal Terminals
- Safety Features
  - » Burst Disc in Cover



USAF-NASA Program Research/Development Announcement (PRDA)

- Five Year Program to Develop Lithium Ion Cells/Batteries for Mars Exploration, Satellites and Aircraft Applications
- Total Program Cost = $13.6 Million with Options / Now $17.3 Million over 6 Years
- YTP developing Control Electronics, Chargers, Electrolyte and Materials
- Lithium Ion Cells Required in 7, 20, 50 and 200 Ah Sizes. All are Prismatic
- These Cells will be Used to Assemble 14, 28, 100 and 270 Volt Batteries with Control Electronics.
- Develop Qualification Units. Flight Hardware Funded Separately

Introduction

- High pulse power capability important for several DOD and commercial applications
  - Directed Energy Weapons (>10 kW/l, >4kW/kg)
  - Aircraft (operation at –40°C)
  - Medical Devices
  - Electric Vehicle (regenerative braking)

Introduction (Cont.)

- Lithium-ion offers high energy and power density, long life, high reliability and safety
  - Not fully optimized for Ultra High Rate performance (>10C)
- Strong effort to identify limiting factors under these conditions
  - Focus on High Rate Pulses at various temperatures
  - Coin cell and 7Ah full-cell results presented.

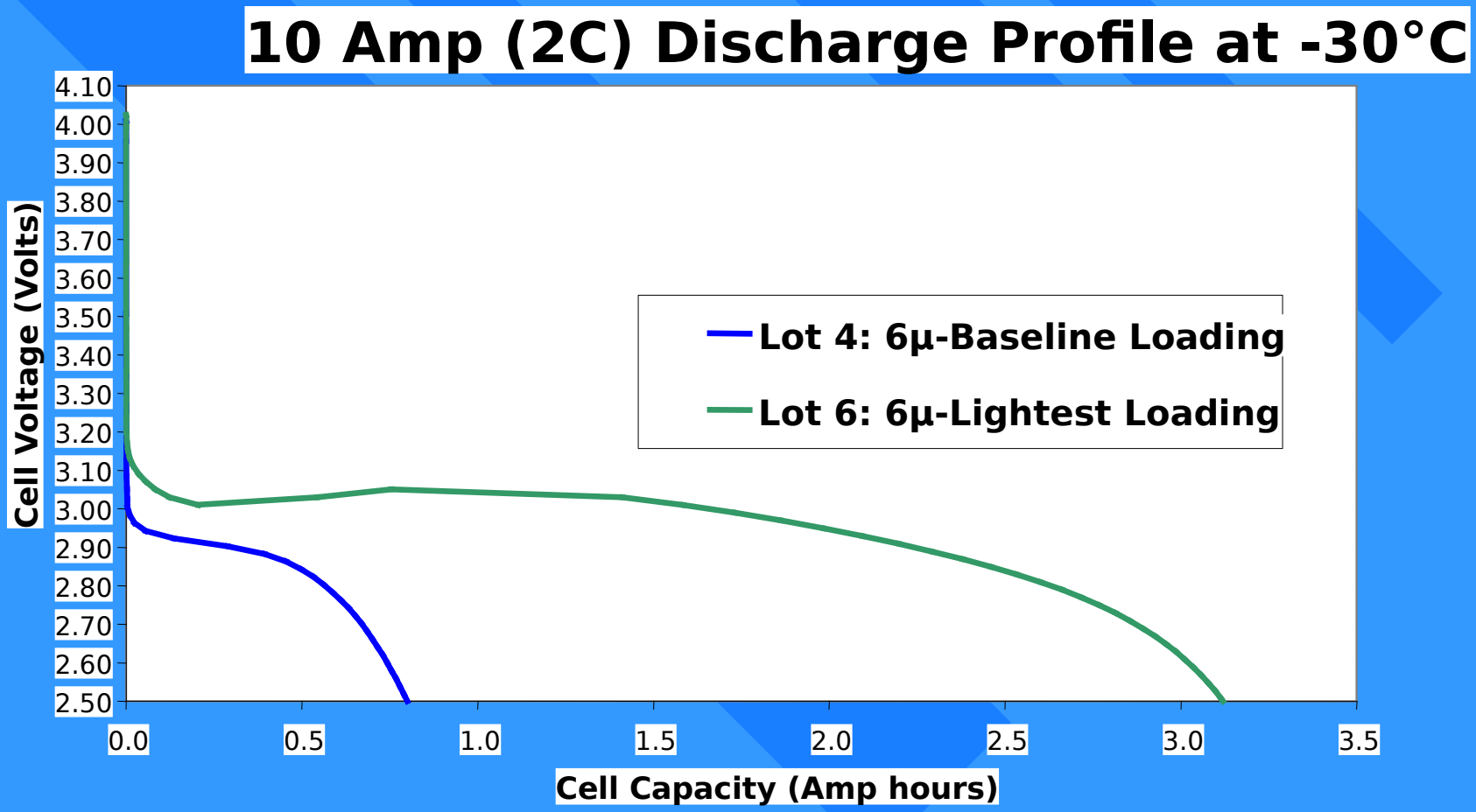
Requirements vs. Capability

Parameter	Requirement	Current Capability	Goal
Pulse Discharge @ 25°C	>10kW/l	8-9 kW/l	>20kW/l
Continuous Discharge @25°C	>50C	20C	50C
Pulse @ -20°C	>15C	10C	20C
Continuous @ -20°C	>10C	5C	>10C

Previous Efforts

- Early research focused on Anode particle size and electrode weight loading
  - Smaller particles = larger surface area = greater Li^+ diffusion
  - Lighter electrode weight loading = thinner electrodes = reduced current density

Previous Efforts – Low Temperature



Lessons Learned from Previous Efforts

- At low temperature and low rates the anode type was found to be a significant factor in polarization
  - The electrode weight loading was not important until the rates increased beyond the 1C level.
  - At 4C and –30°C the electrode weight loading was found to be as important as the anode material. At even higher rates only the weight loading is significant
- Suggests a switch in the limiting factor from the anode to the electrolyte as rate increases at low temperature
  - Change in operating mechanism

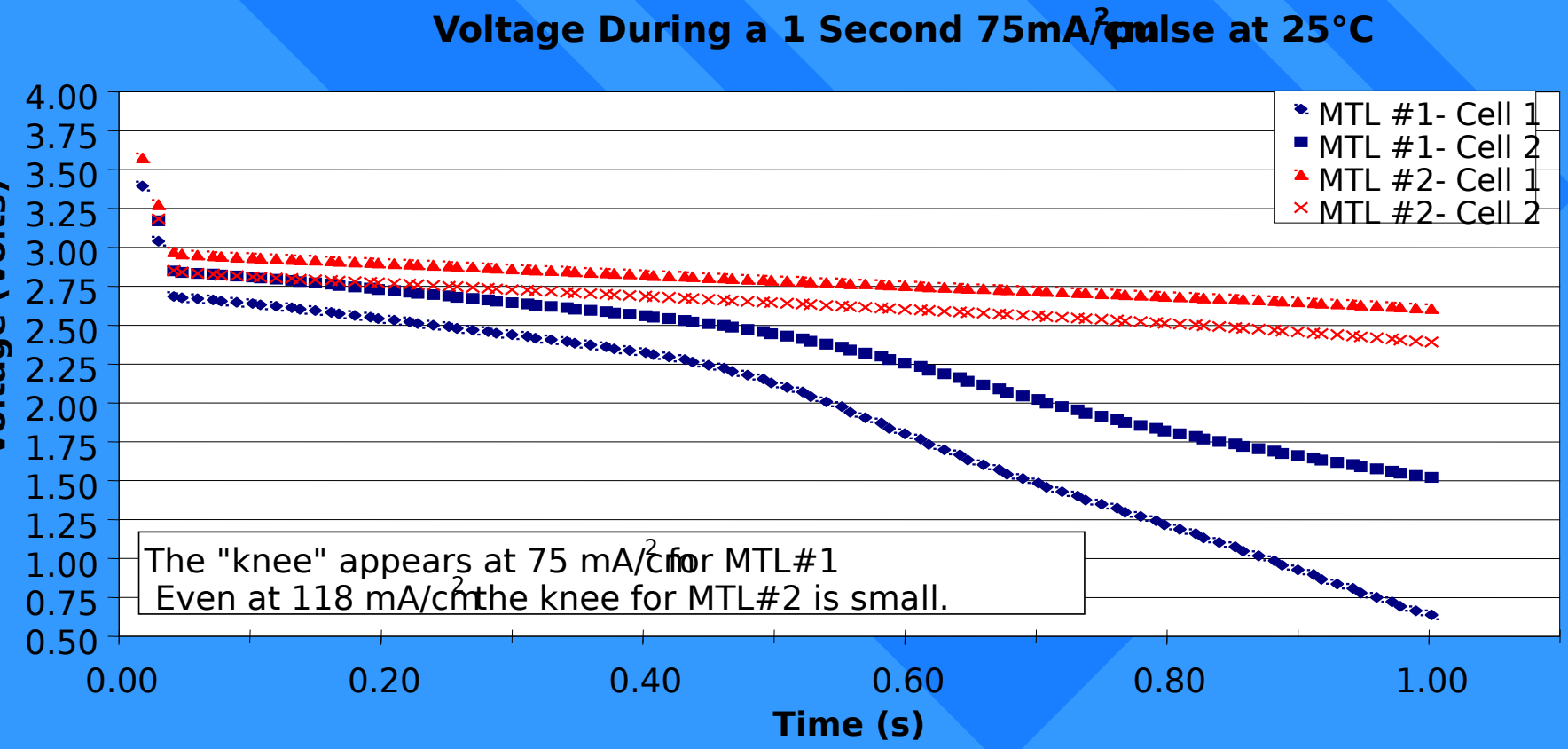
Current Efforts

- Pulse durations of 1 second selected for baseline as they are of the general order of magnitude of Directed Energy Weapons, Aircraft and Medical applications.
  - All low temperature pulses followed low temperature charges.
- Each component was looked at separately.
  - Anode
  - Cathode
  - Electrolyte
  - Separator

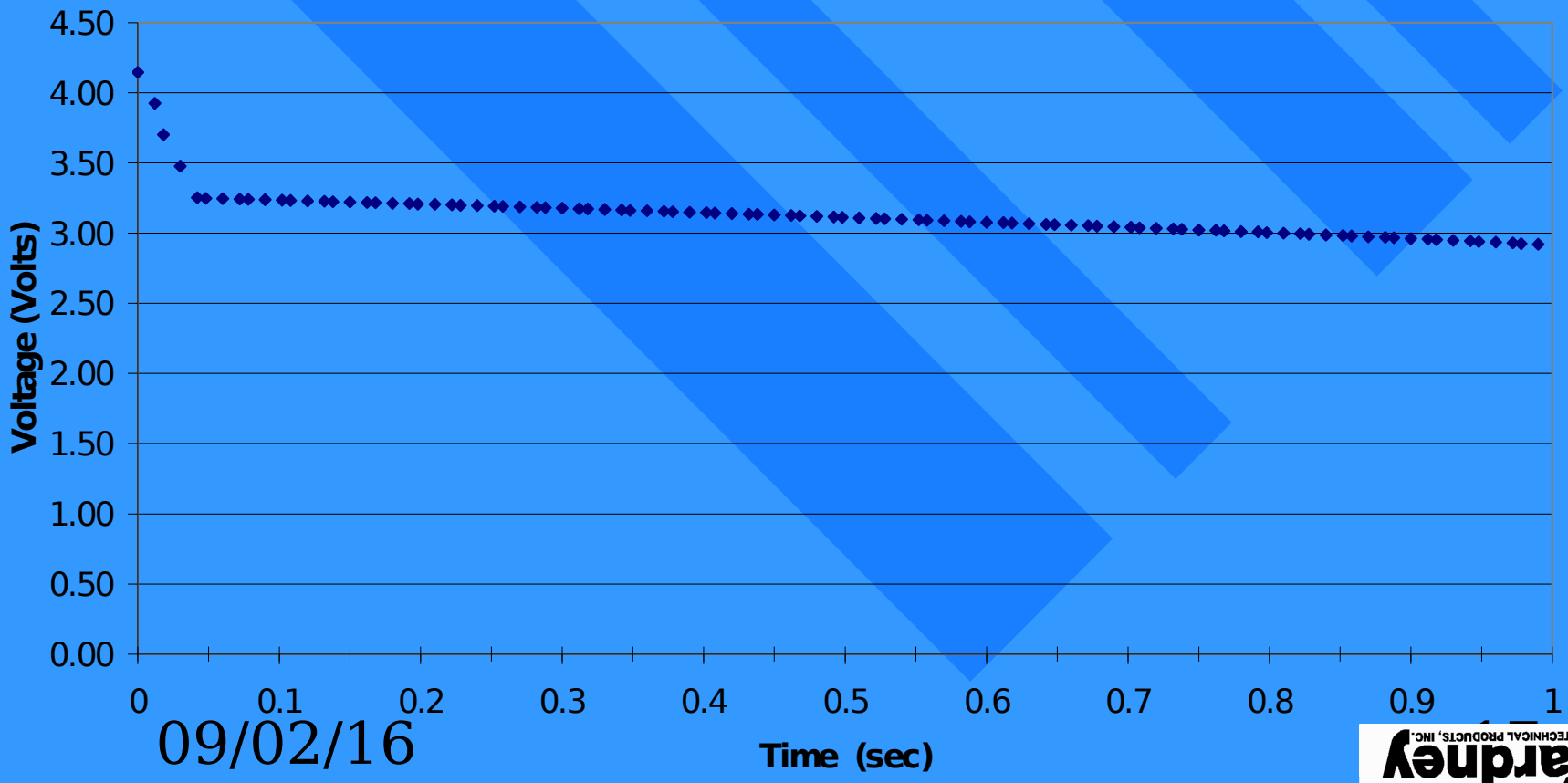
The Cathode…

- Several types of cathode material were evaluated.
  - Various chemistries and manufacturers
  - Substantial differences were found
- Several methods were evaluated at modifying the cathode to improve performance

75 mA/cm² Pulse at 25°C



Optimized 25°C Pulse Discharge
(Material customized to 25°C operation)



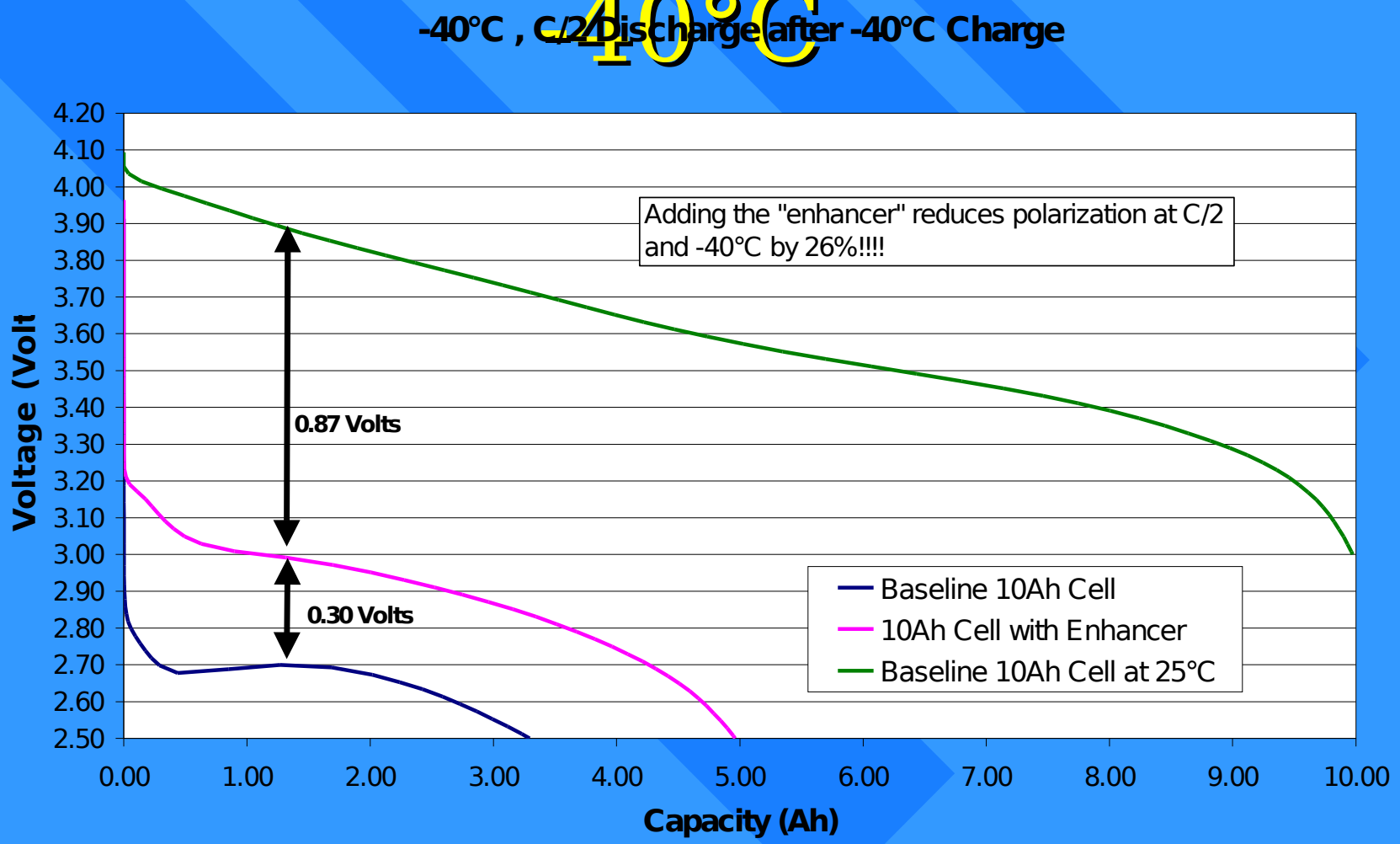
Cathode Modifications

- The effort to improve the cathode materials initially improved both low temperature and moderate temperature results.
  - Ultimately, the refinements diverged into separate modifications for the two temperatures.
- It is evident that custom cathode formulations & manufacturing are needed to support tomorrow's high pulse power demands.

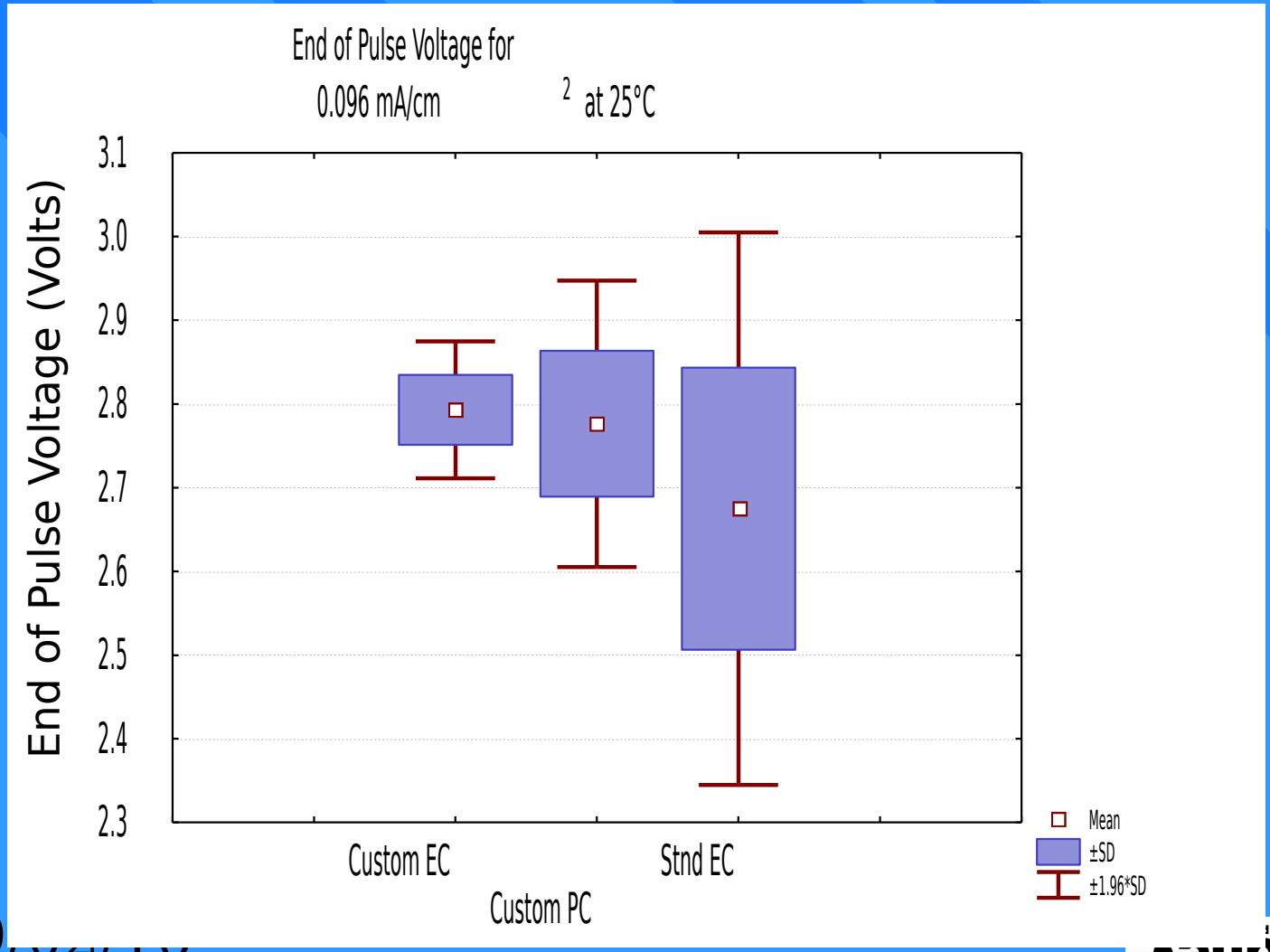
Electrolytes

- The investigation into the separator clearly indicated that since separator is a factor, electrolyte is a factor.
- Materials such as Alkyl Acetates have been shown to improve conductivity at all temperatures.
  - In fact, some EC:MA electrolytes have –20°C conductivities on par with the conductivity of standard electrolytes at 25°C
  - Unfortunately, such electrolytes do not support the formation of “commercially useful” SEI layers.

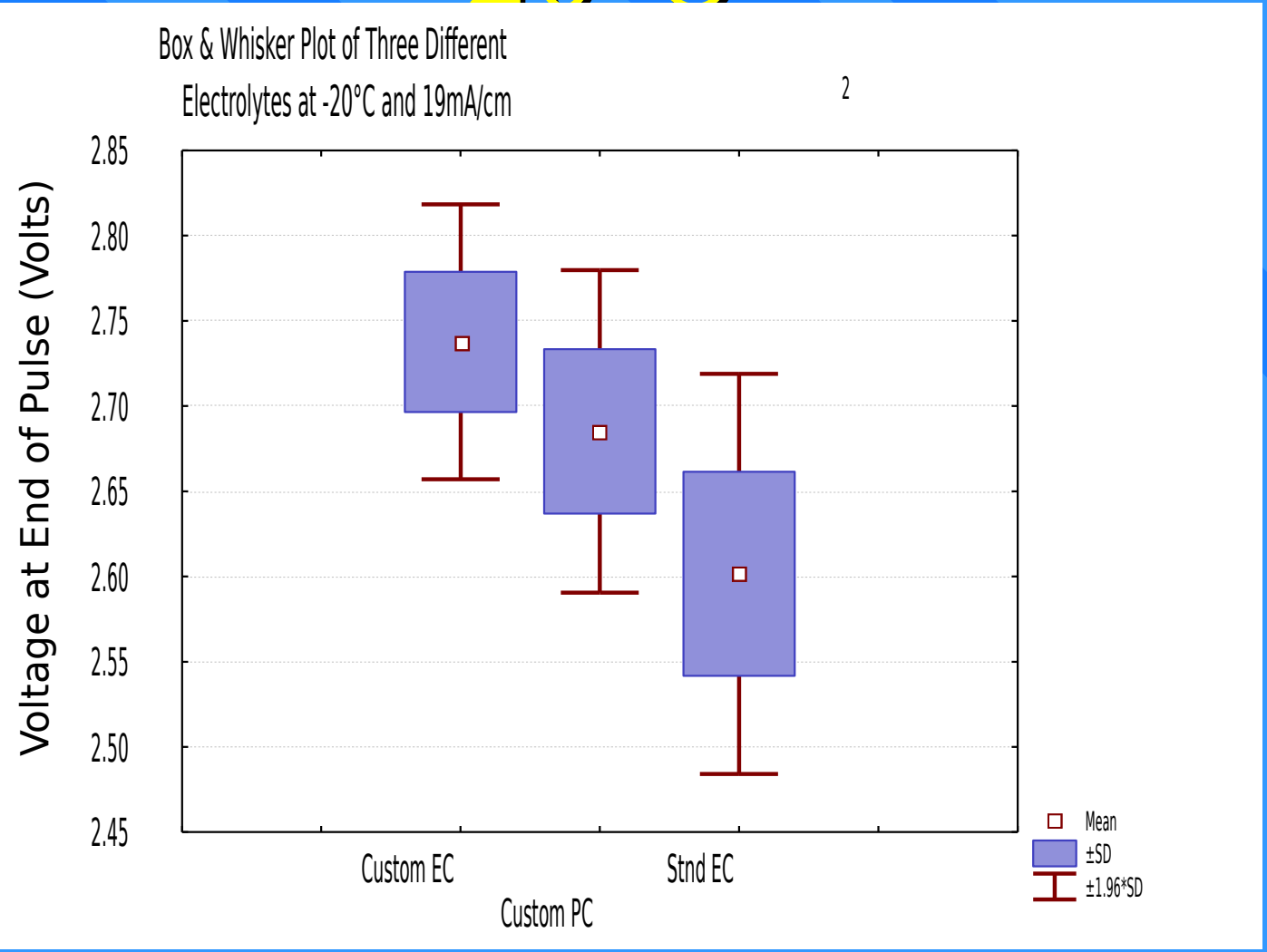
Effect of Electrolyte @ 40°C



Effect of Electrolyte @ +25°C



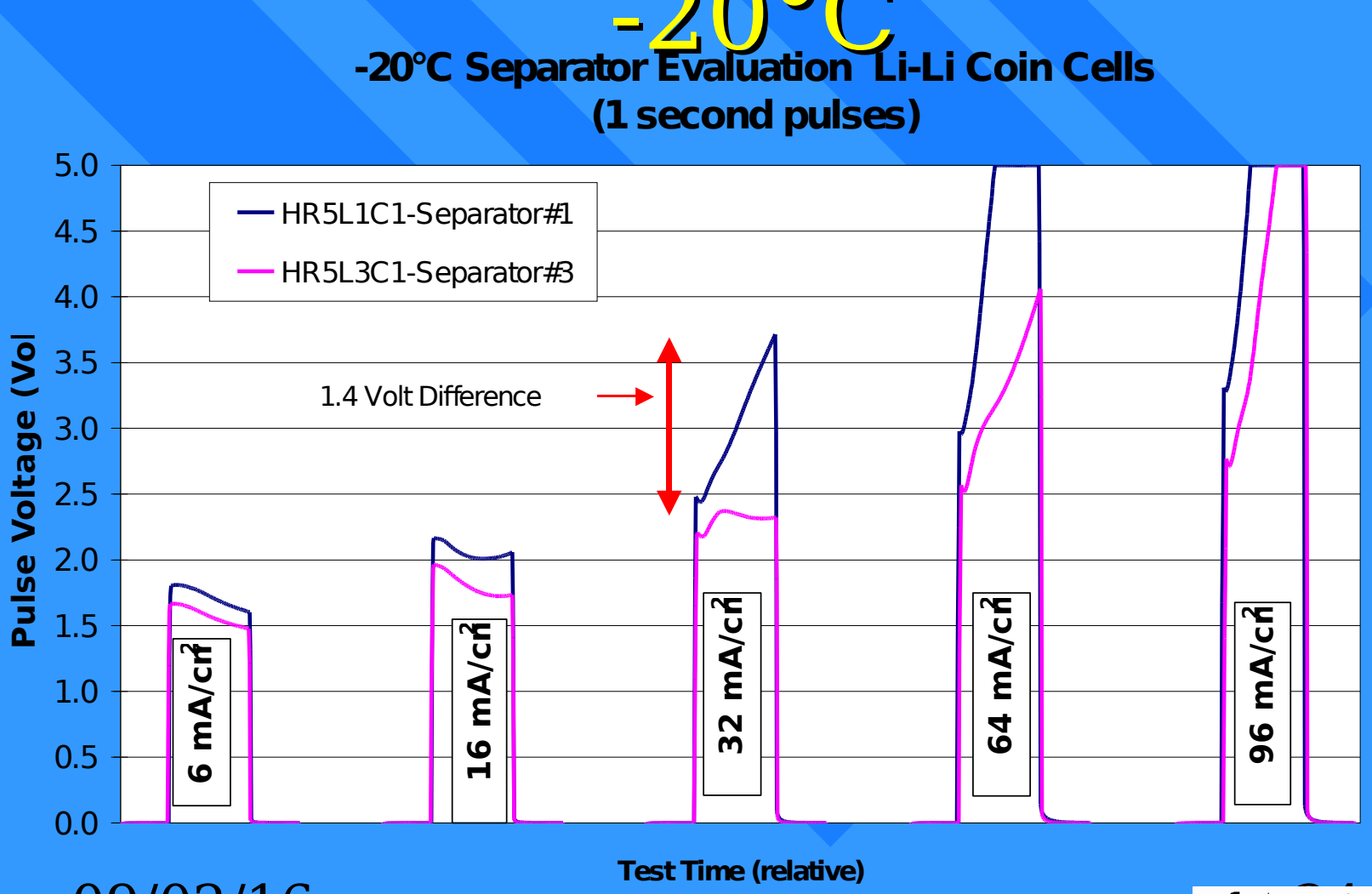
Effect of Electrolyte @ -20°C



Separators…

- Two separate approaches were used to evaluate the effect of the separator.
  - Impedance measurements on Pt-Pt electrodes
    - Showed that the conductivity of electrolyte is 4 to 10 times higher than the conductivity observed through a separator.
  - Li-Li Coin Cell
- Both methods yield the same performance trends
  - Separator effects assumed independent of anode/cathode

Different Separators @ -20°C



Separators….

- In all, 11 separators were evaluated.
  - Some separators were completely incapable of supporting higher currents.
    - » Possibly an intentional feature. Such separators act like a built in fuse.
  - The Separator and Electrolyte are a “system”. It is the conductivity of the separator/electrolyte system that is critical.
    - » High conductivity electrolytes tend to have more problems wetting separators.

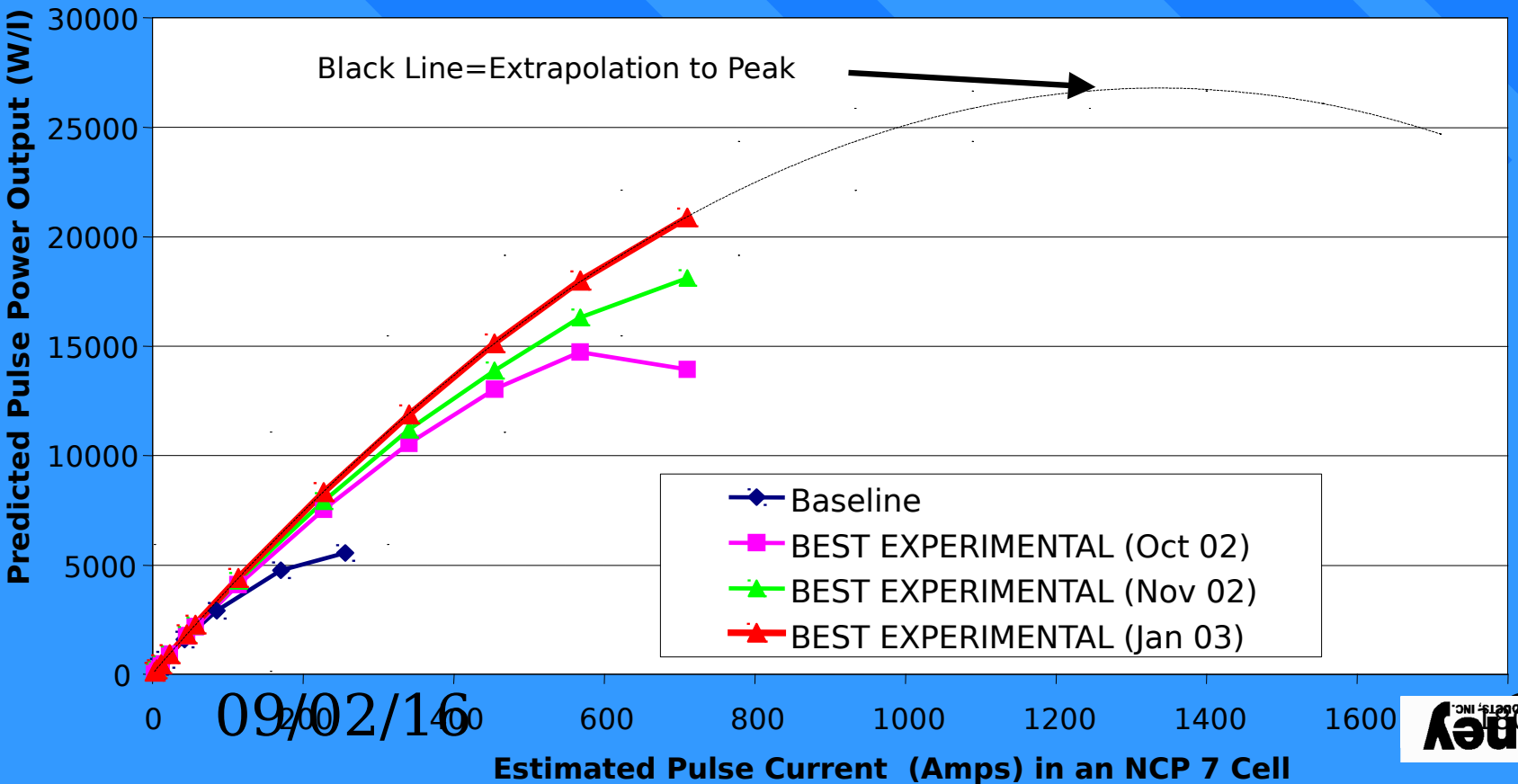
Electrolyte Summary

- Electrolyte and Separator clearly play a role in low temperature pulse performance and retention of that performance with aging and exposure to elevated temperatures.
- High/Room temperature effects not as dramatic
  - Other mechanisms become important
  - However, much of the polarization is still to be accounted for….

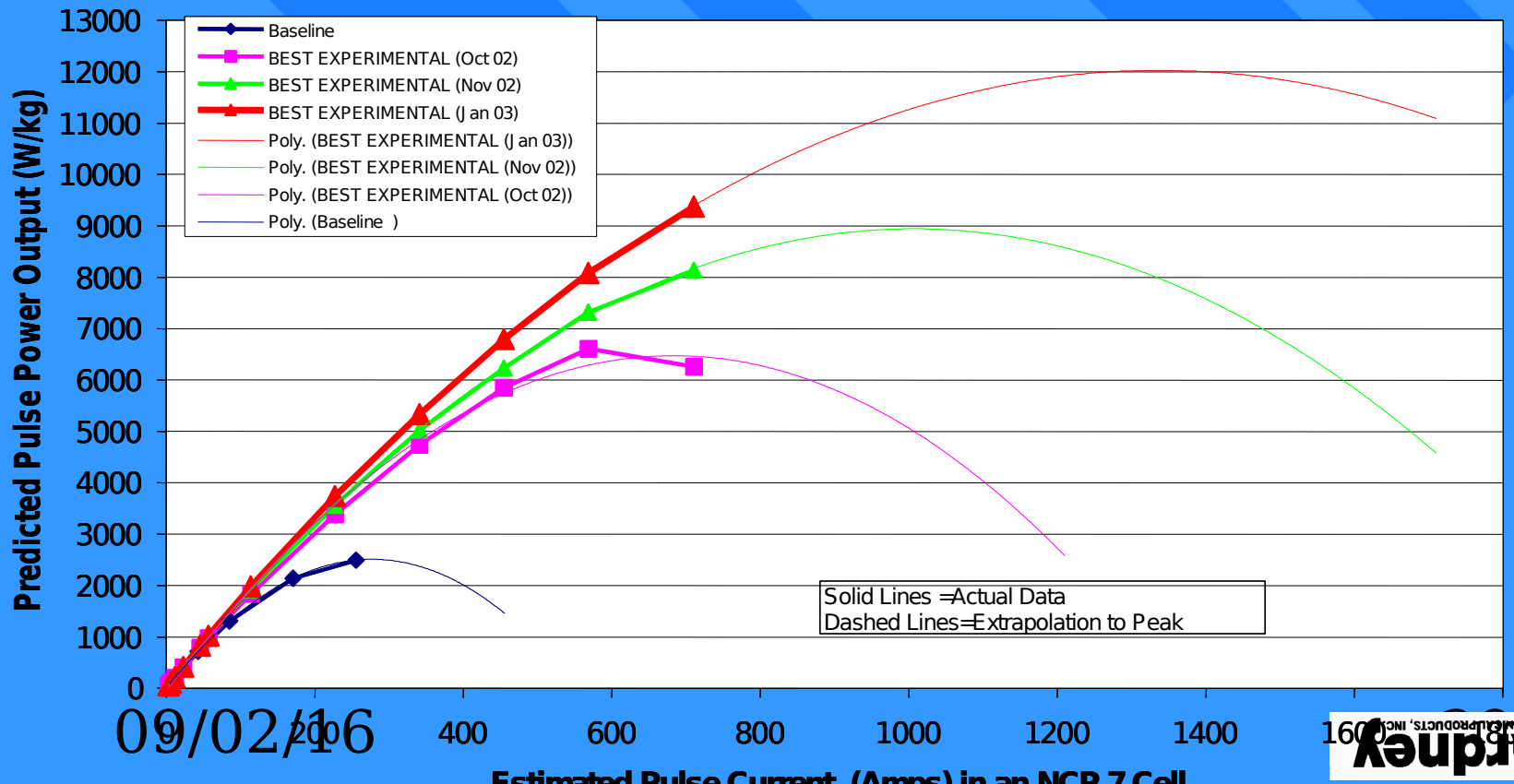
Extrapolation of Results to Full Size Cells

Extrapolation of Results into 7Ah Cells

Summary of High Rate Improvements
(1 Second Pulses at 25°C)



Extrapolation of Results into 7Ah Cells



Summary

- 500% increase in 1 Second Pulse Power demonstrated
  - Power output of 0.45W/cm^2 electrode area
  - Results extrapolate to 12kW/kg and 25kW/l for 1 second pulses
  - Full sized cells currently under test
  - Now addressing mechanical design issues
- Lithium-ion chemistry meeting/exceeding requirements for High Power applications
  - This capability is an enabler for some of these applications

Acknowledgments

- U.S. Air Force
  - Steve Vukson for his continued support of the PRDA (now LiDP) program that served as the starting point for the technology.
    - » Contract: F-33615-98-C-2898